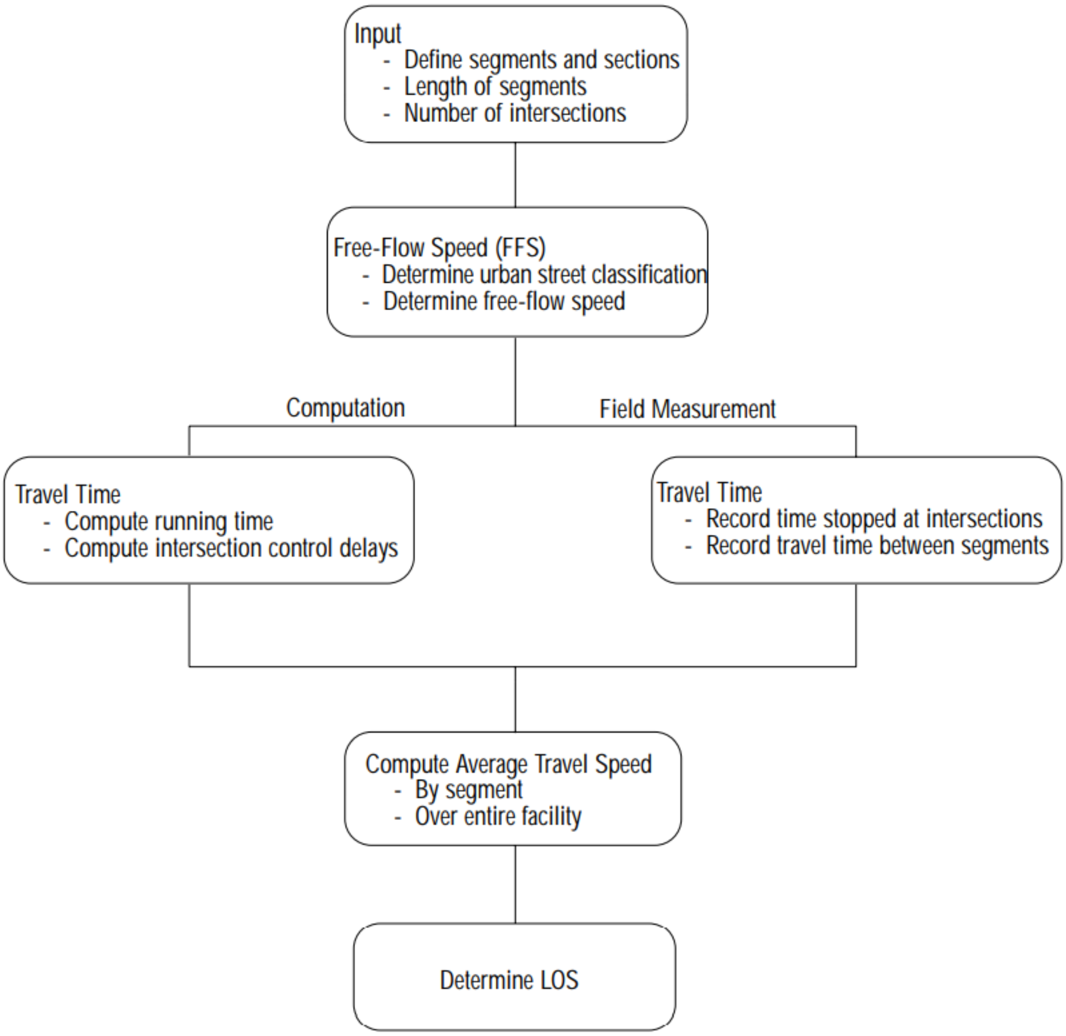
Urban Streets

Introduction

The analyst should be able to investigate the effect of signal spacing, street classification, and traffic flow on LOS. The methodology uses the signalized intersection procedure presented in previous lecture for the through-traffic lane group. By redefining the lane arrangement (e.g., presence or absence of left-turn lanes, number of lanes), the analyst can influence which traffic flow is in the through-traffic lane group as well as the capacity of the lane group. This redefinition, in turn, influences the street LOS by changing the intersection evaluation and possibly the street classification.

EXHIBIT 15-1. URBAN STREET METHODOLOGY



LOS

Urban street LOS is based on average through-vehicle travel speed for the segment or for the entire street under consideration. Travel speed is the basic service measure for urban streets. The average travel speed is computed from the running times on the urban street and the control delay of through movements at signalized intersections.

The control delay is the portion of the total delay for a vehicle approaching and entering a signalized intersection that is attributable to traffic signal operation. Control delay includes the delays of initial deceleration, move-up time in the queue, stops, and reacceleration.

The LOS for urban streets is influenced both by the number of signals per kilometer and by the intersection control delay. Inappropriate signal timing, poor progression, and increasing traffic flow can degrade the LOS substantially. Streets with medium-to-high signal densities (i.e., more than one signal per kilometer) are more susceptible to these factors, and poor LOS might be observed even before significant problems occur.

On the other hand, longer urban street segments comprising heavily loaded intersections can provide reasonably good LOS, although an individual signalized intersection might be operating at a lower level. The term through vehicle refers to all vehicles passing directly through a street segment and not turning.

Exhibit 15-2 lists urban street LOS criteria based on average travel speed and urban street class. It should be noted that if demand volume exceeds capacity at any point on the facility, the average travel speed might not be a good measure of the LOS. The street classifications identified in Exhibit 15-2 are defined in the next section.

EXHIBIT 15-2. URBAN STREET LOS BY CLASS

Urban Street Class	I	II	III	IV
Range of free-flow speeds (FFS)	90 to 70 km/h	70 to 55 km/h	55 to 50 km/h	55 to 40 km/h
Typical FFS	80 km/h	65 km/h	55 km/h	45 km/h
LOS	Average Travel Speed (km/h)			
A	> 72	> 59	> 50	> 41
B	> 56–72	> 46–59	> 39–50	> 32–41
C	> 40–56	> 33–46	> 28–39	> 23–32
D	> 32–40	> 26–33	> 22–28	> 18–23
E	> 26–32	> 21–26	> 17–22	> 14–18
F	≤ 26	≤ 21	≤ 17	≤ 14

Determining Urban Street Class

The first step in the analysis is to determine the urban street's class. This can be based on direct field measurement of the FFS or on an assessment of the subject street's functional and design categories.

If the FFS measurements are not available, the street's functional and design categories must be used to identify its class. The functional category is identified first, followed by the design category.

Determining Running Time

There are two principal components of the total time that a vehicle spends on a segment of an urban street: running time and control delay at signalized intersections. To compute the running time for a segment, the analyst must know the street's classification, its segment length, and its FFS. The segment running time then can be found by using Exhibit 15-3.

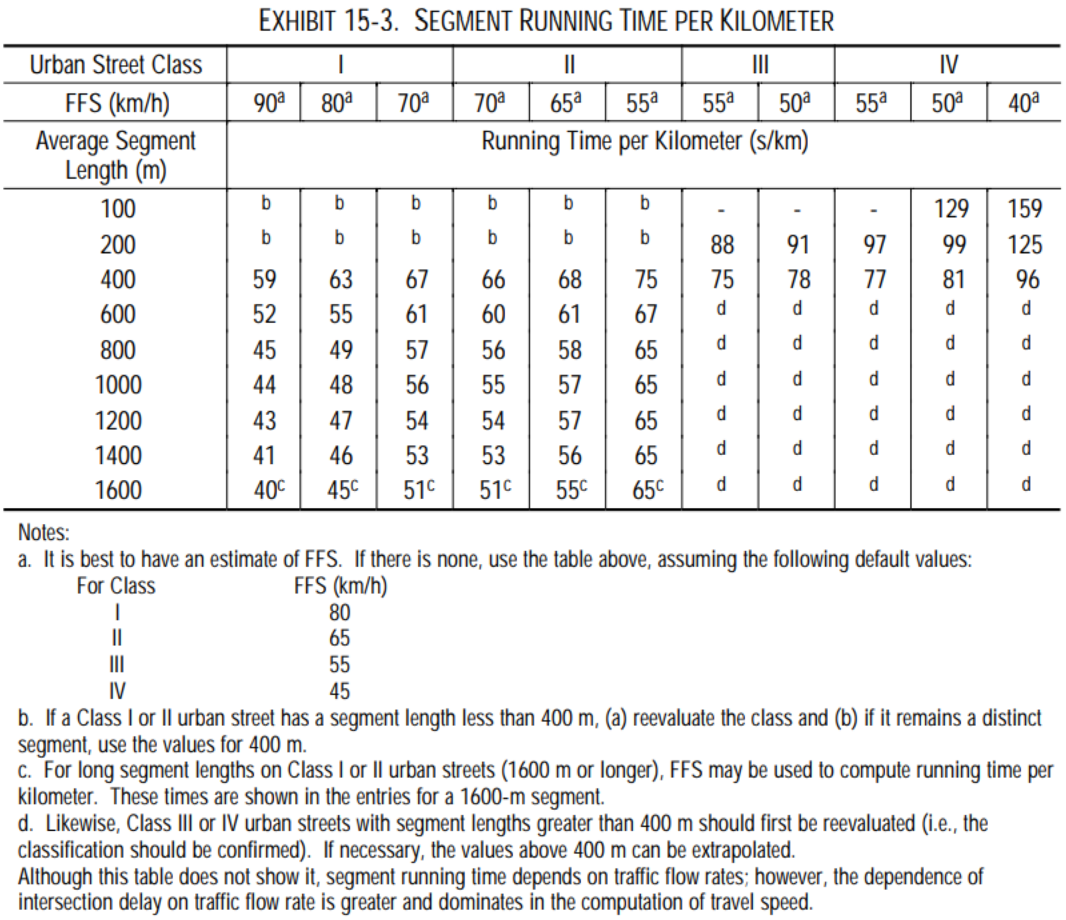


EXHIBIT 15-3. SEGMENT RUNNING TIME PER KILOMETER

Urban Street Class	I			II			III		IV	
FFS (km/h)	90^{a}	80^{a}	70^{a}	70^{a}	65^{a}	55^{a}	55^{a}	50^{a}	55^{a}	50^{a}	40^{a}
Average Segment Length (m)	Running Time per Kilometer (s/km)										
100	b	b	b	b	b	b	-	-	-	129	159
200	b	b	b	b	b	b	88	91	97	99	125
400	59	63	67	66	68	75	75	78	77	81	96
600	52	55	61	60	61	67	d	d	d	d	d
800	45	49	57	56	58	65	d	d	d	d	d
1000	44	48	56	55	57	65	d	d	d	d	d
1200	43	47	54	54	57	65	d	d	d	d	d
1400	41	46	53	53	56	65	d	d	d	d	d
1600	40^{c}	45^{c}	51^{c}	51^{c}	55^{c}	65^{c}	d	d	d	d	d

Notes:

a. It is best to have an estimate of FFS. If there is none, use the table above, assuming the following default values:

For Class	FFS (km/h)
I	80
II	65
III	55
IV	45

b. If a Class I or II urban street has a segment length less than 400 m, (a) reevaluate the class and (b) if it remains a distinct segment, use the values for 400 m.

c. For long segment lengths on Class I or II urban streets (1600 m or longer), FFS may be used to compute running time per kilometer. These times are shown in the entries for a 1600-m segment.

d. Likewise, Class III or IV urban streets with segment lengths greater than 400 m should first be reevaluated (i.e., the classification should be confirmed). If necessary, the values above 400 m can be extrapolated.

Although this table does not show it, segment running time depends on traffic flow rates; however, the dependence of intersection delay on traffic flow rate is greater and dominates in the computation of travel speed.

Within each urban street class there are several influences on actual running time. Exhibit 15-3 shows the effect of street length. In addition, the presence of parking, side friction, local development, and street use can affect running time. In this chapter, these also are assumed to influence the FFS. Direct observation of the FFS, therefore, includes the effect of these factors and, by implication, their effect on the running speed. If it is not possible to observe the FFS on the actual or a comparable facility, default values are given in a note to Exhibit 15-3.

Determining Delay

Computing the urban street or section speed requires the intersection control delays. Because the function of an urban street is to serve through traffic, the lane group for through traffic is used to characterize the urban street.

The control delay for the through movement is the appropriate delay to use in an urban street evaluation. In general, the analyst should have this information because the intersections should have been evaluated individually as part of the overall analysis. Equation 15-1 is used to compute control delay. Equations below are used to compute uniform delay and incremental delay, respectively.

$$d = d_1(PF) + d_2 + d_3$$

$$d_1 = \frac{0.5C\left(1-\frac{g}{C}\right)^2}{1-\left[\min(1,X)\frac{g}{C}\right]}$$

$$d_2 = 900T\left[(X-1)+\sqrt{(X-1)^2+\frac{8kIX}{cT}}\right]$$

where

d = control delay (s/veh);
d_1 = uniform delay (s/veh);
d_2 = incremental delay (s/veh);
d_3 = initial queue delay, see Chapter 16 (s/veh);
PF = progression adjustment factor (Exhibit 15-5);
X = volume to capacity (v/c) ratio for the lane group (also termed degree of saturation);
C = cycle length (s);
c = capacity of lane group (veh/h);
g = effective green time for lane group (s);
T = duration of analysis period (h);

k = incremental delay adjustment for the actuated control; and
I = incremental delay adjustment for the filtering or metering by upstream signals.

Uniform Delay

Equation previously gives an estimate of control delay assuming perfectly uniform arrivals and a stable flow. It is based on the first term of Webster's delay formulation and is accepted as an accurate depiction of delay for the ideal case of uniform arrivals. Values of X greater than 1.0 are not used in the computation of d_1.

Incremental Delay

Equation previously estimates the incremental delay due to no uniform arrivals and individual cycle failures (i.e., random delay) as well as delay caused by sustained periods of oversaturation (i.e., oversaturation delay). The equation interrelates the degree of saturation (X) of the lane group, the duration of the analysis (T), the capacity of the lane group (c), and the signal control (k). The equation assumes that all demand flow has been serviced in the previous analysis period—that is, there is no initial queue. The incremental delay term is valid for all degrees of saturation.

Initial Queue Delay

When a queue from the previous period is present at the start of the analysis, newly arriving vehicles experience initial queue delay. This delay results from the additional time required to clear the initial queue. Its magnitude depends on the size of the initial queue, the length of the analysis period, and the v/c ratio for that period.

Arrival Type and Platoon Ratio

A critical characteristic that must be quantified for the analysis of an urban street or signalized intersection is the quality of the progression. The parameter that describes this characteristic is the arrival type, AT, for each lane group. This parameter approximates the quality of progression by defining six types of dominant arrival flow.

Arrival Type 1 is characterized by a dense platoon of more than 80 percent of the lane group volume arriving at the start of the red phase. This arrival type represents network links that experience a poor rate of progression due to various conditions, including lack of coordination.

Arrival Type 2 is characterized by a moderately dense platoon that arrives in the middle of the red phase or by a dispersed platoon of 40 to 80 percent of the lane group volume arriving throughout the red phase. This arrival type represents an unfavorable progression along an urban street.

Arrival Type 3 consists of random arrivals in which the main platoon contains less than 40 percent of the lane group volume. This arrival type represents operations at no interconnected, signalized intersections with highly dispersed platoons. It also may be used to represent a coordinated operation with minimal benefits of progression.

Arrival Type 4 consists of a moderately dense platoon that arrives in the middle of the green phase or of a dispersed platoon of 40 to 80 percent of the lane group volume arriving throughout the green phase. This arrival type represents a favorable progression along an urban street.

Arrival Type 5 is characterized by a dense to moderately dense platoon of more than 80 percent of the lane group volume arriving at the start of the green phase. This arrival type represents a highly favorable progression, which may occur on routes with a low-to moderate number of side street entries and which receive high priority in signal timing.

Arrival Type 6 is reserved for exceptional progression quality on routes with near ideal characteristics. It represents dense platoons progressing over several closely spaced intersections with minimal or negligible side street entries.

Arrival type is best observed in the field but can be approximated by examining time-space diagrams for the street. The arrival type should be determined as accurately as possible because it has a significant impact on delay estimates and LOS determination. Although there are no definitive parameters to quantify arrival type, the ratio defined by Equation below is useful.

$$R_p = P\left(\frac{C}{g}\right)$$

where

R_P = platoon ratio,
P = proportion of all vehicles arriving during green,
C = cycle length (s), and
g = effective green time for movement (s).

The value for P may be estimated or observed in the field, whereas C and g are computed from the signal timing. The value of P may not exceed 1.0. The approximate ranges of R_p relate to arrival type as shown in Exhibit 15-4, which also suggests default values for use in subsequent computations.

EXHIBIT 15-4. RELATIONSHIP BETWEEN ARRIVAL TYPE AND PLATOON RATIO (R_p)

Arrival Type	Range of Platoon Ratio (R_p)	Default Value (R_p)	Progression Quality
1	≤ 0.50	0.333	Very poor
2	> 0.50–0.85	0.667	Unfavorable
3	> 0.85–1.15	1.000	Random arrivals
4	> 1.15–1.50	1.333	Favorable
5	> 1.50–2.00	1.667	Highly favorable
6	> 2.00	2.000	Exceptional

Progression Adjustment Factor

Good signal progression results in the arrival of a high proportion of vehicles on the green; poor signal progression results in the arrival of a low proportion of vehicles on the green. The progression adjustment factor, PF, applies to all coordinated lane groups, whether the control is pretimed or nonactuated in a semiactuated system. Progression primarily affects uniform delay; for this reason, the adjustment is applied only to d1. The value of PF may be determined by Equation below.

$$PF = \frac{(1-P)f_{PA}}{\left(1-\frac{g}{C}\right)}$$

where

PF = progression adjustment factor,
P = proportion of all vehicles arriving during green,
g/C = effective green-time ratio, and
f_{PA} = supplemental adjustment factor for platoon arrival during the green.

The value of P may be measured in the field or estimated from the time-space diagram. The value of PF also may be computed from measured values of P using the default values for f_{PA}. Alternatively, Exhibit 15-5 may be used to determine PF as a function of the arrival type based on the default values for P and f_{PA} associated with each arrival type. If PF is estimated by Equation below, its value may not exceed 1.0 for Arrival Type 4 with extremely low values of g/C; as a practical matter, PF should be assigned a maximum value of 1.0 for Arrival Type 4.

EXHIBIT 15-5. PROGRESSION ADJUSTMENT FACTORS FOR UNIFORM DELAY CALCULATION

Green Ratio (g/C)	Arrival Type (AT)					
	AT 1	AT 2	AT 3	AT 4	AT 5	AT 6
0.20	1.167	1.007	1.000	1.000	0.833	0.750
0.30	1.286	1.063	1.000	0.986	0.714	0.571
0.40	1.445	1.136	1.000	0.895	0.555	0.333
0.50	1.667	1.240	1.000	0.767	0.333	0.000
0.60	2.001	1.395	1.000	0.576	0.000	0.000
0.70	2.556	1.653	1.000	0.256	0.000	0.000
f_{PA}	1.00	0.93	1.00	1.15	1.00	1.00
Default, R_p	0.333	0.667	1.000	1.333	1.667	2.000

Notes:
$PF = (1 - P)f_{PA}/(1 - g/C)$.
Tabulation is based on default values of f_p and R_p.
$P = R_p * g/C$ (may not exceed 1.0).
PF may not exceed 1.0 for AT 3 through AT 6.

The progression adjustment factor, PF, requires knowledge of offsets, travel speeds, and intersection signalization. When delay is estimated for future coordination, particularly when analyzing alternatives, Arrival Type 4 should be assumed as a base condition for coordinated lane groups (except for left turns), and Arrival Type 3 should be assumed for all uncoordinated lane groups.

For movements made from exclusive left-turn lanes on exclusive phases, the progression adjustment factor usually should be 1.0 (i.e., Arrival Type 3). However, if the signal coordination provides for a progression of left-turn movements, the progression adjustment factor should be computed from the estimated arrival type, as for through movements. When the coordinated left turn is part of protected-permitted phasing, only the effective green for the protected phase should be used to determine the progression adjustment factor, since the protected phase normally is associated with platooned coordination. A flow-weighted average of P should be used in determining PF when a time-space diagram is used and lane group movements have different levels of coordination.

Incremental Delay Adjustment for Actuated Controls

In previous equation the term k incorporates the effect of the controller on delay. For pretimed signals, a k-value of 0.50 is used. This is based on queuing with random arrivals and on uniform service equivalent to the lane group capacity. Actuated controllers, however, can tailor the green time to the current demand, reducing the overall incremental delay. The delay reduction depends in part on the controller's unit extension and the degree of saturation. Research has indicated that lower unit extensions (i.e., snappy intersection operation) result in lower values of k and d_2. However, when the degree of saturation approaches 1.0, an actuated controller will act like a pretimed controller, producing k-values of 0.50 at degrees of saturation greater than or equal to 1.0. Exhibit 15-6 illustrates the k-values recommended for actuated controllers with different unit extensions and degrees of saturation.

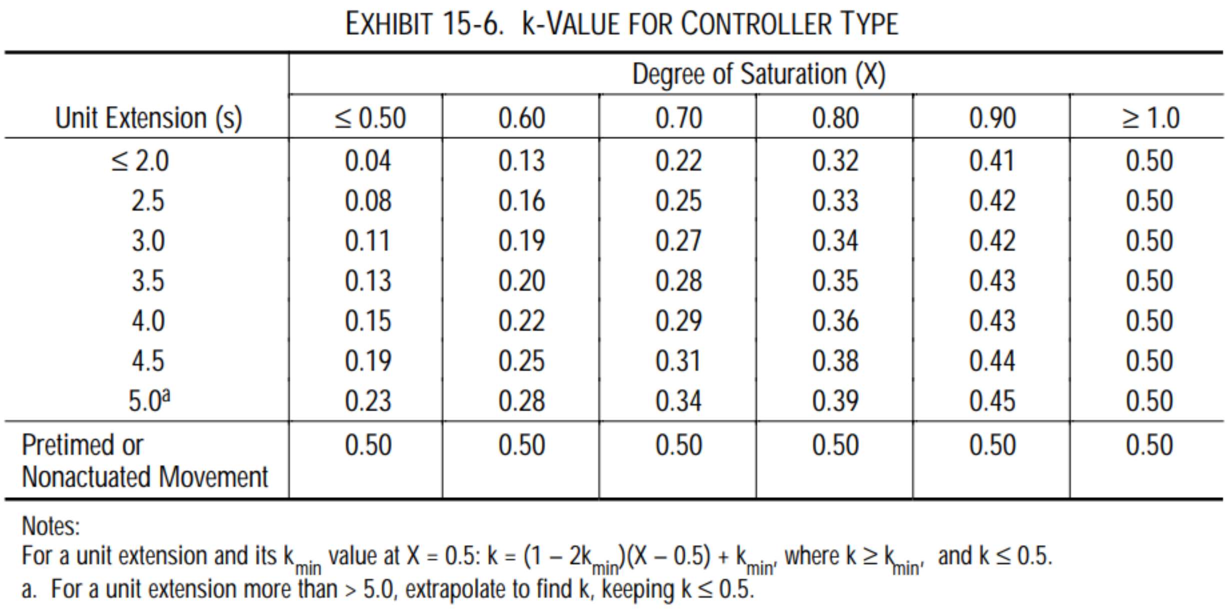


EXHIBIT 15-6. k-VALUE FOR CONTROLLER TYPE

Unit Extension (s)	Degree of Saturation (X)					
	≤ 0.50	0.60	0.70	0.80	0.90	≥ 1.0
≤ 2.0	0.04	0.13	0.22	0.32	0.41	0.50
2.5	0.08	0.16	0.25	0.33	0.42	0.50
3.0	0.11	0.19	0.27	0.34	0.42	0.50
3.5	0.13	0.20	0.28	0.35	0.43	0.50
4.0	0.15	0.22	0.29	0.36	0.43	0.50
4.5	0.19	0.25	0.31	0.38	0.44	0.50
5.0[a]	0.23	0.28	0.34	0.39	0.45	0.50
Pretimed or Nonactuated Movement	0.50	0.50	0.50	0.50	0.50	0.50

Notes:
For a unit extension and its k_{min} value at X = 0.5: $k = (1 - 2k_{min})(X - 0.5) + k_{min}$, where $k \geq k_{min}$, and $k \leq 0.5$.
a. For a unit extension more than > 5.0, extrapolate to find k, keeping $k \leq 0.5$.

For unit extension values not listed in Exhibit 15-6, the k-values may be interpolated. If the formula in Exhibit 15-6 is used, the k_{min} value (i.e., the k-value for X = 0.50) first should be interpolated for the unit extension and then the formula should be used. Exhibit 15-6 may be extrapolated for unit extension values beyond 5.0 s, but the extrapolated k-value never should exceed 0.50.

Upstream Filtering or Metering Adjustment Factor, I

The incremental delay adjustment term I in Equation 15-4 accounts for the effects of filtered arrivals from upstream signals. An I-value of 1.0 is used for an isolated intersection (i.e., one that is 1.6 km or more from the nearest upstream signalized intersection). This value is based on a random number of vehicles arriving per cycle so that the variance in arrivals equals the mean.

An I-value of less than 1.0 is used for no isolated intersections. This reflects the way that upstream signals decrease the variance in the number of arrivals per cycle at the subject (i.e., downstream) intersection. As a result, the amount of delay due to random arrivals is reduced. Exhibit 15-7 lists I-values for no isolated intersections. The values of I in this exhibit are based on Xu, the weighted v/c ratio of all upstream movements contributing to the volume in the subject intersection lane group. This ratio is computed as a weighted average with the v/c ratio of each contributing upstream movement weighted by its volume. For the analysis of urban street performance, it is sufficient to approximate Xu as the v/c ratio of the upstream through movement.

EXHIBIT 15-7. RECOMMENDED I-VALUES FOR LANE GROUPS WITH UPSTREAM SIGNALS

	Degree of Saturation at Upstream Intersection, X_u						
	0.40	0.50	0.60	0.70	0.80	0.90	≥ 1.0
I	0.922	0.858	0.769	0.650	0.500	0.314	0.090

Note: $I = 1.0 - 0.91 X_u^{2.68}$ and $X_u \leq 1.0$.

Determining Travel Speed

Equation below is used on each segment and on the entire section to compute the travel speed.

$$S_A = \frac{3600L}{T_R + d}$$

where

S_A = average travel speed of through vehicles in the segment (km/h);
L = segment length (km);
T_R = total of running time on all segments in defined section (s); and
d = control delay for through movements at the signalized intersection (s).

In special cases, there might be midblock delays caused by vehicle stops at pedestrian crosswalks, or other delays caused by bus stops or driveways. These other delays can be added to the denominator of Equation previous.

Determining LOS

There is a distinct set of urban street LOS criteria for each urban street class. These criteria are based on the differing expectations that drivers have for the different kinds of urban streets. Both the FFS of the urban street class and the intersection LOS definitions are taken into account. Exhibit 15-2 gives the LOS criteria for each urban street class. These criteria vary with the class: the lesser the urban street (i.e., the higher its classification number), the lower the driver's expectation for that facility and the lower the speed associated with the LOS. Thus, a Class III urban street provides LOS B at a lower speed than a Class I urban street. The analyst should be aware of this in explaining before-and-after assessments of urban streets that have been upgraded. If reconstruction upgrades a facility from Class II to Class I, it is possible that the LOS will not change (or may even decline), despite the higher average speed and other improvements, because the expectations would be higher. The concept of overall urban street LOS is meaningful only when all segments on the urban street are in the same class.

Sensitivity of Results to Input Variables

The following speed-flow curves illustrate the sensitivity of travel speed to

- FFS,
- v/c ratio,
- Signal density, and
- Urban street class.

Exhibits 15-8 through 15-11 use the v/c ratio to plot the through movement in the peak direction at the critical intersection on an urban street. The critical intersection is the intersection with the highest through v/c ratio. The through capacity of an intersection on the urban street is computed using Equation below.

$$c = N * s * \frac{g}{C}$$

where

c = capacity of the through lane (veh/h),
N = number of through lanes at the intersection,
s = adjusted saturation flow per through lane (veh/h), and
g/C = effective green time per cycle for the through movement at the intersection.

The capacity of an urban street is defined for a single direction of travel as the capacity of the through movement at its lowest point (usually at a signalized intersection). The capacity is determined by the number of lanes, the saturation flow rate per lane (influenced by geometric design and demand factors), and the green time per cycle for the through movement at the intersection.

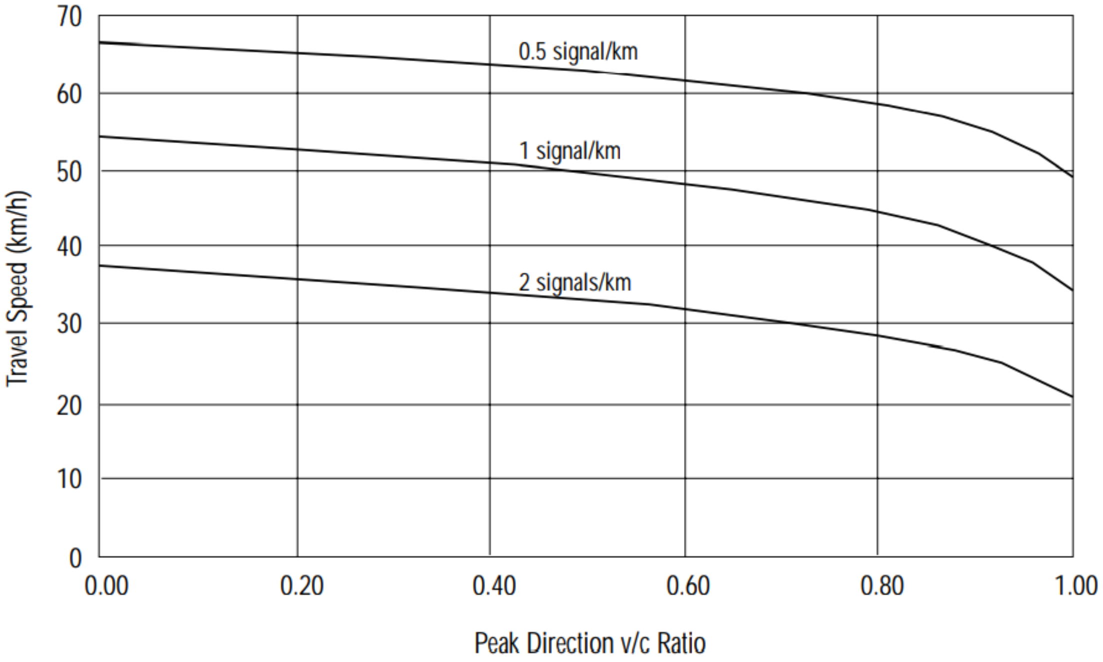
The cycle length also can affect the urban street capacity. Longer cycle lengths generally allow a greater portion of the available green time for the through movement, but still provide for pedestrian clearance times, phase-change intervals, and vehicle clearance times.

Signal coordination (i.e., the quality of progression) generally improves urban street speeds and LOS. Improved coordination, however, does not generally increase urban street capacity by itself—the g/C ratio for the major street also must be improved by the coordination plan.

Increased signal density generally lowers urban street speeds and LOS but does not affect capacity, unless the added signals have lower g/C ratios, or lower saturation flow rates, for the through movements.

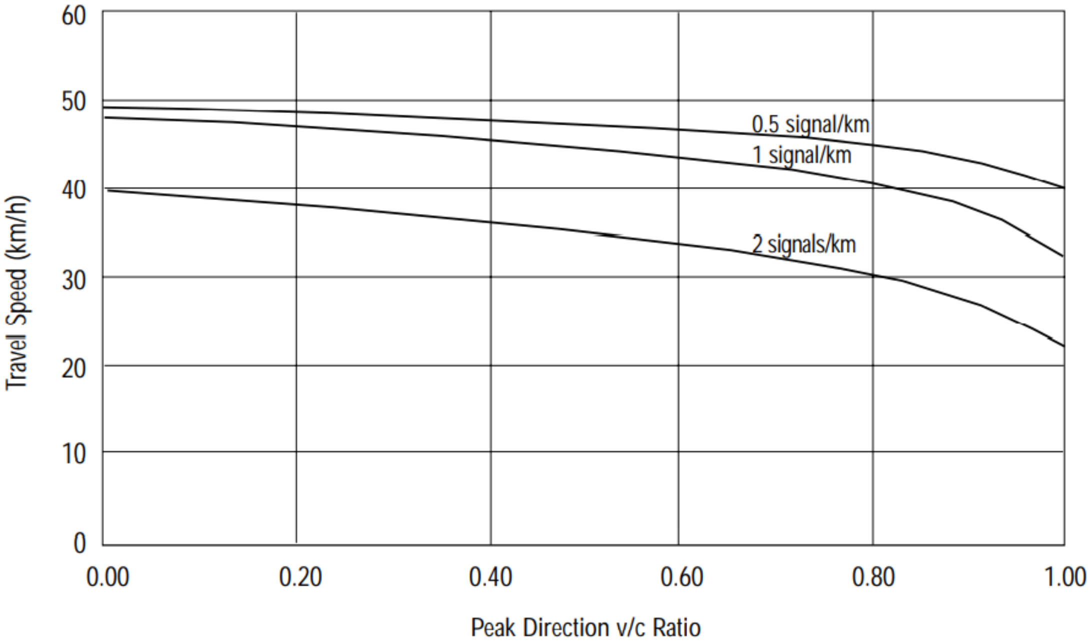
Exhibits 15-8, 15-9, 15-10, and 15-11 show how signal density and intersection v/c ratios for urban street through movements affect the mean travel speeds for the different street classes. The signal timing and street design assumptions used in computing these specific curves are listed as footnotes. For computational convenience, it was assumed that all signals on each street had identical demand, signal timing, and geometric characteristics. Different assumptions would yield different curves.

EXHIBIT 15-8. SPEED-FLOW CURVES FOR CLASS I URBAN STREETS
(SEE FOOTNOTE FOR ASSUMED VALUES)



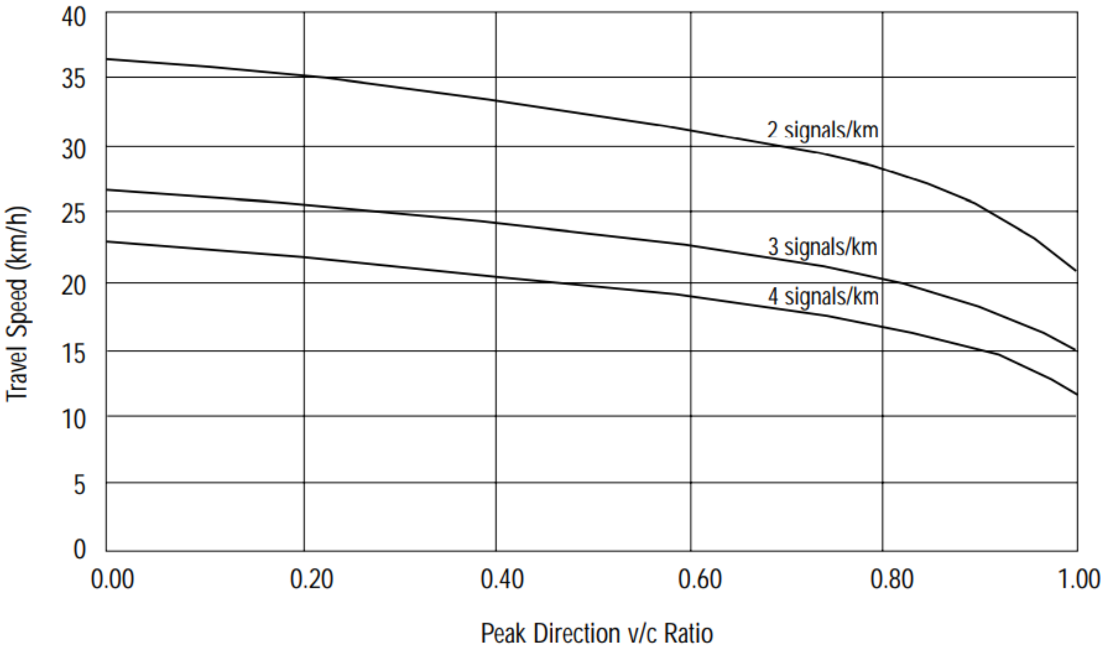
Note:
Assumptions: 80-km/h midblock FFS, 10-km length, 120-s cycle length, 0.45 g/C, Arrival Type 3, isolated intersections, adjusted saturation flow rate of 1,700 veh/h, 2 through lanes, analysis period of 0.25 h, pretimed signal operation.

EXHIBIT 15-9. SPEED-FLOW CURVES FOR CLASS II URBAN STREETS
(SEE FOOTNOTE FOR ASSUMED VALUES)



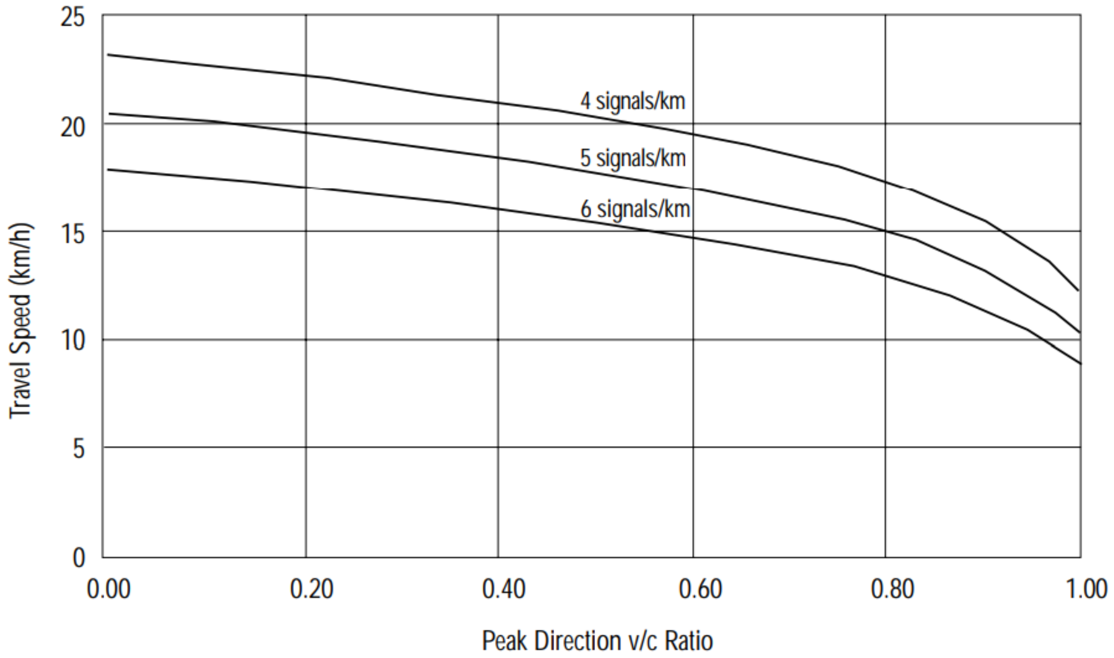
Note:
Assumptions: 65-km/h midblock FFS, 10-km length, 120-s cycle length, 0.45 g/C, Arrival Type 3, isolated intersections, adjusted saturation flow rate of 1,700 veh/h, 2 through lanes, analysis period of 0.25 h, pretimed signal operation.

EXHIBIT 15-10. SPEED-FLOW CURVES FOR CLASS III URBAN STREETS
(SEE FOOTNOTE FOR ASSUMED VALUES)



Note:
Assumptions: 55-km/h midblock FFS, 10-km length, 120-s cycle length, 0.45 g/C, Arrival Type 3, isolated intersections, adjusted saturation flow rate of 1,700 veh/h, 2 through lanes, analysis period of 0.25 h, pretimed signal operation.

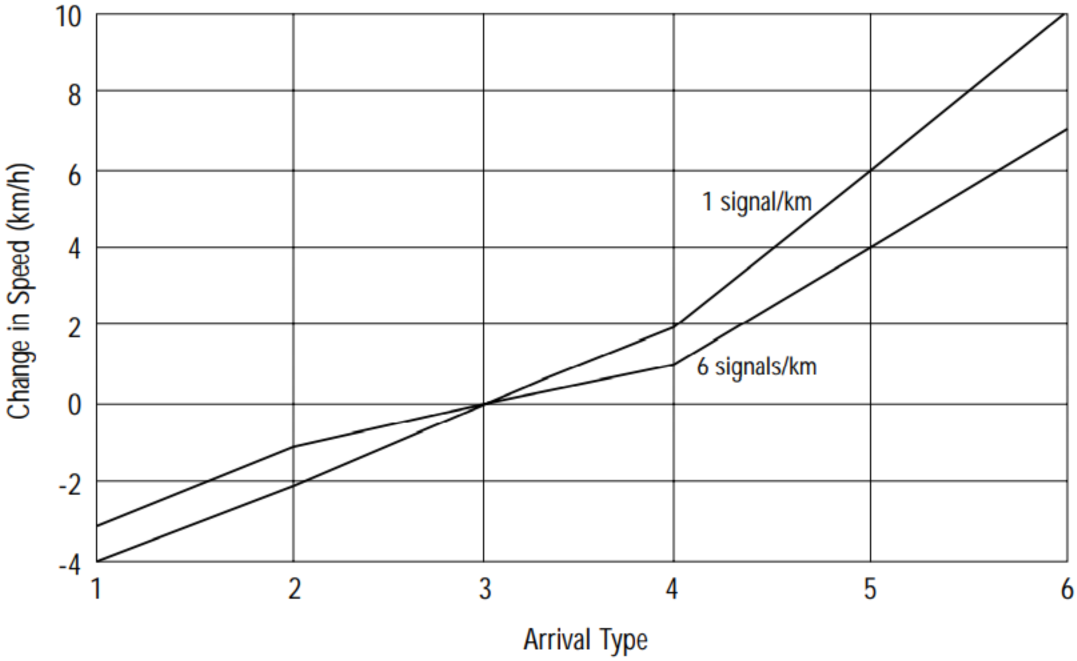
EXHIBIT 15-11. SPEED-FLOW CURVES FOR CLASS IV URBAN STREETS
(SEE FOOTNOTE FOR ASSUMED VALUES)



Note:
Assumptions: 50-km/h midblock FFS, 10-km length, 120-s cycle length, 0.45 g/C, Arrival Type 4, isolated intersections, adjusted saturation flow rate of 1,700 veh/h, 2 through lanes, analysis period of 0.25 h, pretimed signal operation.

Exhibit 15-12 illustrates the sensitivity of estimated speed to arrival types.

EXHIBIT 15-12. CHANGE IN MEAN SPEED FOR ARRIVAL TYPES
(SEE FOOTNOTE FOR ASSUMED VALUES)



Note:
Assumptions: Urban street Class III, 56-km/h midblock FFS, 10-km length, 120-s cycle, 0.45 g/C, pretimed signals, 0.925 peak-hour factor (PHF), exclusive left-turn lanes, 12 percent left turns.